DUAL CONCENTRIC ROBOTIC HIGH PERFORMANCE AUTOMATED TAPE CARTRIDGE SYSTEM

BACKGROUND OF THE INVENTION

1. Technical Field:

The present invention relates generally to electronic media storage and retrieval and in particular to an improved method and apparatus for restoring and retrieving large amounts of data contained within tape cartridges.

2. Description of Related Art:

Storage library systems are capable of storing and rapidly retrieving large quantities of information stored in storage media cartridges. Such storage library systems often use robotic mechanisms to improve the speed of information retrieval and reliability of maintaining the storage library cartridge inventory.

An automatic cartridge library is a system used for handling large amounts of information in a data processing system. These types of systems store and manage large numbers of standardized cassettes containing magnetic tape on which data is recorded. Typically, an automated cartridge library is comprised of arrays of uniquely identified cells in which each cell contains a single tape cartridge. These cells are arranged in arrays or racks for holding many of these cartridges.

Each cartridge has identifying information, such as a bar code. A robotic arm, having an optical system for selecting the correct cartridge, is operable within the automated cartridge library to locate a particular cell, retrieve a tape cartridge from the cell, convey the tape cartridge to a tape drive, and insert the tape cartridge into a tape drive.

In many applications, the amount of data is large enough that multiple library storage modules are employed in which each module contains cell arrays and a robotic arm, but does not require additional host computers and does not contain a tape drive. These multiple library storage units are typically arranged adjacent to one another and pass-through ports are provided for passing tape cartridges from one library storage module to an adjacent library storage module. In these systems, a problem exists in automated library systems to facilitate loading and unloading of cartridges when the number of cartridges and drive devices are greater than some threshold of reasonable performance. As a result, a bottleneck is created because the robotic arm within a library module is unable to keep up the requests from a host. For example, exchange rates of over 1,000 tape cartridges per hour strains presently available cartridge tape library systems.

Therefore, it would be advantageous to have an approved method and apparatus for an automated tape cartridge library system having higher performance and better reliability.

SUMMARY OF THE INVENTION

The present invention provides a data storage and retrieval system. In a preferred embodiment, the data storage and retrieval system includes a polygonal array of cells that are inwardly disposed with openings configured to receive data storage units. A first robot unit to transport a data storage unit to and from the polygonal array of cells is located within the polygonal array of cells. A second robot unit is also located within the polygonal array of cells to transport a data storage unit to and from the polygonal array of cells. The second robot unit manipulates the data storage units placed in the cylindrical array of cells independently of the first robot unit.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 shows an automated cartridge system (ACS) **100** according to one embodiment of the present invention;

Figure 2 shows the interface between the host computers and the LSMs;

Figure 3 shows an LSM in greater detail;

Figure 4 shows a cross-sectional view of an automated memory cartridge system **400** according to the present invention;

Figures 5A-5B show perspective views of a robot suitable for use as robot **110** or robot **150** in **Figure 4**;

Figure 6 shows a block diagram of the robot control system in accordance with the present invention;

Figures 7-12 shows alternate configurations of the dual concentric robots **410** and **450** in accordance with the present invention;

Figure 13 illustrates a concentric robots having redundant arms in accordance with the present invention;

Figure 14 illustrates an alternate embodiment in which there are four concentric independently rotatable

arms within a library storage module **1410** in accordance with the present invention;

Figure 15 shows a schematic diagram of four independently rotatable arms with off-centered axes of rotation in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference now to the figures, wherein like characters designate like or corresponding parts throughout the several views, there is shown in **Figure 1** an automated cartridge system (ACS) **100** in which a preferred embodiment of the present invention may be implemented. The ACS **100** is designed to operate with an IBM, or IBM-compatible host computer **102** capable of communication with a conventional 327X-type terminal controller **104** as will be described in further detail herein below. Comprised generally of a library management unit (LMU) **106** and a library storage module (LSM) **108**, the ACS **100**, through its associated host software component (HSC) **110**, enables storage and retrieval of magnetic tape cartridges for use by the host computer **102** across a conventional channel **112**.

Each LMU **106** serves as the library controller and provides the interface between from one to sixteen host computers **102** and up to 16 LSMs **108**, as shown in **Figure 2**.

Turning now to **Figure 2**, a block diagram of a distributed data processing system is depicted in accordance with a preferred embodiment of the present invention. LMU **106** thus acts as an outboard controller and interprets commands from host computers **102**, relaying appropriate instructions to LSM **108** via a control path (shown in solid lines) and a library control unit (LCU) **109**. On the other and, the read/write data path (dashed

lines) comes directly from the host computer **102**, through a tape control unit **111** to the tape transports **150** as will be described further herein below, thereby separating control signals from data signals.

Each LSM **108** provides the necessary mechanisms for automated cartridge handling. It not only provides the storage area for magnetic tape cartridges utilized in the system, but also includes an optical system for identifying the correct cartridge, a servo-controlled, electromechanical means of selecting the proper cartridge and delivering it o the correct tape drive, and a suitable housing to ensure operator safe4ty and data security.

As shown in greater detail in **Figure 3**, a diagram of a LSM is shown in which the present invention may be implemented. LSM **108** is comprised generally of an outer housing **113** which includes a plurality of wall segments **114** attached to floor plates (not shown) and disposed about a vertical axis **A**. A cylindrical array **134** of storage cells **132** is concentrically arranged about axis **A**, mounted upon the wall segments **114** of the outer housing **113**. A clearance door **138** allows for access into the interior of LSM **108**. The robotics that manipulate the cartridges within LSM **108** are not depicted in **Figure 3**.

Turning now to **Figure 4**, a cross-sectional view of a library storage module is depicted in accordance with a preferred embodiment of the present invention. Library storage module (LSM) **400** may be implemented as LSM **108** in **Figure 1**. Automated memory cartridge system **400** includes

two robots **410** and **450**. Robot **410** is mounted to floor **402** of automated memory cartridge system **400** by way of a number of bolts (not shown) through support **412**. Robot **450** is mounted to the ceiling **404** of automated cartridge system **400** by way of a number of bolts (not shown) through support **452**. Both robot **410** and robot **450** share the same theta axis **406** of rotation (i.e., dual concentric robots). Each robot, robot **410** and robot **450** operates within a cylindrical or polygonal library **490** containing a plurality of cartridge arrays **492** arranged cylindrically or in a polygonal shape. A major axis is an axis within a polygonal array such as cartridge arrays **492**. The major axis is usually, but not always, centrally located within the polygonal array. Furthermore, robot **410** and robot **450** are capable of rotating about center axis **406** approximately two full turns before encountering a mechanical stop. This rotation is a "theta" movement. Collision avoidance is provided by software control, such as robotic control system **600** described below, which control and monitors activities of robot **410** and robot **450** and will limit travel of robot **410** and robot **450** to a location just short of the mechanical stops.

Robot **410**, in addition to support **412**, also includes a theta drive **414**, an arm **416**, a Z-channel **418**, a Z-transport **420**, a Z-motor (not shown), and a hand **422**. Similarly, robot **450**, in addition to its support **452**, also includes a theta drive **454**, an arm **456**, a Z-channel **458**, a Z-transport **460**, a Z-motor (not shown), and a hand **462**. The purpose of the Z transport mechanism is to

provide a means of moving the hand **422** and **462** in a vertical direction. Theta Drive **414** is attached to support **412** and includes a motor that turns an arm **416** about axis **406**. Similarly, theta drive **454** is attached to support **452** and includes a motor that turns an arm **458** about axis **406**.

Hands **422** and **462** provide the actual handling of the cartridges (not shown). Each hand, hand **422** and hand **462**, is attached to a transport that can be moved up and down on its respective Z-channel **418** and **458** (Z move). Each hand, hand **422** and hand **462**, is capable of reaching out, gripping a cartridge, and pulling the cartridge out of its storage cell. Hands **422** and **462** can then be moved to another location through a combination of theta and Z moves and placed in another cell, a tape drive, or some other device located within the LSM **400**.

Robot **410** and robot **450** are essentially identical with minor differences in the way certain parts are assembled to provide proper orientation for the upper and lower hand assemblies. Robots and LSMs such as those described herein may be obtained from Storage Tek with such modifications as to achieve the apparatus of the present invention. Perspective views of a robot suitable for use as robot **410** or robot **450** are shown in **Figures 5A** and **5B**. **Figure 5A** shows the robot from an orientation 180 degrees removed from the orientation shown in **Figure 5B**.

More details about the construction and operation of the robots **410**, **450** and hands **422**, **462** as well as other features of automatic storage and retrieval systems may

be found in U.S. Patent No. 4,932,826 issued to Moy, *et al.* which is incorporated herein by reference.

Each robot, robot **410** and robot **450**, has an absolute position detection device that receives power from the opposite robot's supply. This potentially low-resolution device need not be the primary feedback element for rotational position control. The detected absolute position is made available to both robot **410** and robot **450**. The primary purpose of the absolute position devices is collision avoidance during full speed operation of both robots **410** and **450**. The sensors enable both robots **410** and **450** to operate simultaneously at full speed thus almost doubling performance of the library **490**. However, if one robot **410** or robot **450** is rendered disabled, the first mode of collision avoidance is for that robot to be commanded to move clear of the functioning robot's path. In the event that the disabled robot cannot evade potential collision with the remaining functional robot, use is made of the absolute position detection by the active robot. Any action that is not obstructed by the disabled robot is completed at full performance speeds. An action that is obstructed by the disabled robot is carried out at full speed until the vicinity of the disabled robot is reached. The disabled robot is then pushed to a safe area by the active robot at reduced speeds. The absolute position devices are used secondarily during initialization for determining orientation of the two robots.

Turning now to **Figure 6**, there is shown a block diagram of the robot control system **600** in accordance

with the present invention. The presence of the two robots **410** and **450** not only provides for high performance but also establishes redundant hardware for improve reliability. Along with the redundant robotics are redundant electronics and power. The main electronics (robot controllers) **602**, **612** and processors **604**, **606**, **614**, and **616** have crossover capability so that in the event of failure of one, the other can operate both robots **410**, **450**. The system **600** also contains two power supplies with dual line cords so power to the library can come from two different building circuits. Cards are hot pluggable to provide maximum up time in the event of failure. In addition to redundant hardware, code updates may be loaded without interrupting operation of the library.

Two digital signal processing (DSP) processors are used to control each robot, one is on the controller and one is on the hand. Processors **606** and **608** control robot hand **422** while processors **616** and **618** control robot hand **462**. Processors **608** and **618** are hand processors used in conjunction with the vision system used to decode cartridge labels, and hand position as determined from targets on the storage arrays. Also, processors **608** and **618** are used to control the reach and grip functions of the hand. A second DSP processor resides within the library control unit (LCU) electronics for each robot. Processors **606** and **616** control the theta and Z robot axes as well as providing direct communications to the hand DSP processors **608** and **618**. Both sets of DSP processors are optimized to run in a real-time environment.

A host interface processor (HIP) **604**, **614** provides the interface between the external control environment for host **620** and host **630** and the LCU DSP processors **606** and **616**. The HIP operation environment is multitasking and the two HIPs **606** and **616** provide fail-over capability.

Returning now to **Figure4**, in addition to twin robots **410** and **450**, library **400** contains mechanisms to facilitate insertion and removal of cartridges by the operator. This operation is accomplished through the use of a cartridge access port (CAP) which provides the convenience of loading and unloading through the use of cartridge magazines. The library storage module also has the ability to pass and receive cartridges between other libraries through the use of a cartridge exchange mechanism.

Thus, the present invention utilizing dual concentric robots is able to provide exchange rates of over 1,000 per hour. Each of the two robots has access to the same media and the access is essentially non-reliant on the second robot's activities. Furthermore, access to all drives in the system is equally shared by both robots to the greatest extent possible.

Turning now to **Figures 7-12**, alternate configurations of dual concentric robot **410** and robot **450** are illustrated in accordance with the present invention. For clarity, the library storage module, robotic hands, and other details are not shown in these views.

In **Figure 7** a cross sectional view of dual concentric robots with one robot mounted to the ceiling

and one to the floor with fixed motors is illustrated in accordance a preferred embodiment of the present invention. A support **702** is mounted to floor **704** of the library storage module and a column **706** is attached to support **702**. A sleeve **708** fits and turns around bearings **710** in column **706**. A motor **712** is attached to column **706** and turns a belt (not shown) which in turn, rotates sleeve **708**. Sleeve **708** is attached to arm **714** which is in turn attached to Z-channel **716**. The rotation of sleeve **708** causes the Z-channel **716** to rotate. A second support **720** is attached to the ceiling **722** of library storage module and a second column **724** is attached to second support **720**. A second sleeve **726** fits around second column **724** and rotates on bearings **728** in second column **724**. A second motor **730** is attached to column **724** and turns a belt (not shown) which in turn rotates sleeve **726**. Sleeve **726** is connected to arm **732**, which is, in turn, connected to Z-channel **734**. The rotation of sleeve **726** causes Z-channel **734** to rotate.

In **Figure 8** a cross sectional view of dual concentric robots with one robot mounted to the ceiling and one to the floor with motors mounted to the z-column is illustrated in accordance with a preferred embodiment of the present invention. A support **802** is attached to floor **804** of library storage module and a column **806** is attached to support **802**. A sleeve **808** fits around column **806** and rotates on bearings **810** in column **806**. A motor **812** is attached to sleeve **808** and is also attached to Z-channel **814**. Motor **812** turns a belt (not shown) which loops around column **806** causing motor **812** and, in turn,

Z-channel **814** to rotate about column **806**. A second support **832** is attached to ceiling **834** of library storage module and a second column **836** is attached to second support **832**. A second sleeve **838** fits around column **806** and rotates on bearings **840** in second column **836**. A second motor **842** is attached to second sleeve **838** and is also attached to Z-channel **844**. Second motor **842** turns a belt (not shown) which loops around second column **836** causing second motor **842** and, in turn, Z-channel **844** to rotate about second column **836**.

In **Figures 9** a cross sectional diagram of dual concentric robots both mounted to the floor with inline motors is illustrated in accordance with a preferred embodiment of the present invention. A support **902** is mounted to floor **904** of the library storage module. The motors driving the theta movements of each arm are placed in-line within column **906** that is attached to support **902**. One motor is mounted above the other motor. The lower motor is comprised of stator **908**, bearings **916**, and a rotor **940**. The upper motor is comprised of stator **910**, bearings **922**, and rotor **930**. The stators **908** and **910** are fixed in position, i.e., attached to support **902** via column **906**. Rotor **930** is attached to arm **918** which is in turn connected to Z-channel **914** and rotates about stator **910**. Rotor **940** is attached to arm **912** which is in turn connected to Z-channel **920** and rotates about stator **916**. Thus, the rotors **930** and **940** allow for theta movement of arms **918** and **912**. Bearings **916** allow rotor **940** to turn around stator **908** and bearings **922** allow rotor **930** to

turn around stator **910**. The Z-channels **914** and **920** may be attached to robotic hands (not shown).

In **Figure 10** a cross sectional diagram of dual concentric robots both mounted to the floor having external motors is illustrated in accordance with a preferred embodiment of the present invention. A support **1002** is attached to the floor **1004** of the library storage module. An external motor **1006** is attached to a column **1008** to drive the theta movement of arm **1010**. Arm **1010** is attached to a sleeve **1012** which fits around column **1008** and turns over lubricated bearings **1014** in column **1008**. Also attached to arm **1010** is Z-channel **1016** to which the robotic hand (not shown) attaches. A second external motor **1020** is attached to column **1008** above the first motor **1006** to drive the theta movement of arm **1022**. Arm **1022** is attached to a second sleeve **1024**, which fits around column **1008** and turns over lubricated bearings **1026** in column **1008**. Also attached to arm **1022** is Z-channel **1028** to which a robotic hand (not shown) may be attached.

Figure 11, illustrates dual concentric robots with end drives for theta rotation in accordance with a preferred embodiment of the present invention. A support **1102** is attached to the floor **1104** of the library storage module. A motor **1112** is also attached to support **1102**. A rotating member **1108** fits into a slot **1110** in support **1102**, which allows rotating member **1108** to rotate freely about axis **1150**. A motor **1112** is attached to support **1102** and turns a belt (not shown) which, in turn, rotates rotating member **1108** about axis **1150**. Rotating member

1108 is attached to an arm **1114**, which is attached to Z-channel **1116**. The rotation of rotating member **1108** rotates Z-channel **1116**. A second arm **1118** has a slot **1120** which fits over rotating member **1108** and is also attached to Z-channel **1122**. Second arm **1118** provides support to Z-channel **1122** and is able to rotate freely around and independently of rotating member **1108**.

A second support **1132** is attached to ceiling **1134** of the library storage module. A second motor **1136** is also attached to second support **1132**. A second rotating member **1138** fits into a second slot **1140** in second support **1132**, which allows second rotating member **1138** to rotate freely about axis **1150**. A second motor **1142** is attached to second support **1132** and turns a belt (not shown) which, in turn, rotates second rotating member **1138** about axis **1150**. Second rotating member **1138** is attached to an third arm **1144** which is attached to Z-channel **1122**. The rotation of rotating member **1138** rotates Z-channel **1122**. A fourth arm **1148** has a slot **1146** which fits over rotating member **1138** and is also attached to Z-channel **1116**. Fourth arm **1148** provides support to Z-channel **1116** and is able to rotate freely around and independently of rotating member **1138**. Thus independent theta rotation of both Z-channels **1116** and **1122** is achieved.

Figure 12 illustrates dual concentric robots having inner **1202** and outer **1206** drive shafts in accordance with a preferred embodiment of the present invention. An inner drive shaft **1202** has a bearing **1204** at a lower extremity which fits into the floor (not shown) of the

library storage module. Inner drive shaft **1202** is cylindrically disposed within an outer drive shaft **1206**. The outer drive shaft **1206** is connected to a belt **1208** which is connected to motor **1210** which provides rotation to turn outer drive shaft **1206**. Outer drive shaft **1206** is connected to a lower arm **1212** which is connected to Z-channel **1214**. Z-channel **1214** is connected to robotic hand **1216**.

Inner drive shaft **1202** is connected to a belt **1220** which is connected to motor **1222** that provides rotation to turn inner drive shaft **1202**. Inner drive shaft **1202** is connected to an upper arm **1224** that is connected to Z-channel **1226**. Z-channel **1226** is connected to a robotic hand **1228**. Rotation of the inner drive shaft **1202** provides rotation of robotic hand **1228** within the library storage module. At an upper extremity of inner drive shaft **1202** is a second bearing **1230** which connects to the ceiling (not shown) of the library storage module, thus supporting inner drive shaft **1202**.

Figure 13 illustrates concentric robots having redundant arms in accordance with a preferred embodiment of the present invention. A lower arm **1302** supporting two Z-channels **1304** and **1306** rotates about an axis **1308** within library storage module **1310**. An upper arm **1312** is situated above lower arm **1302** to rotate about axis **1308** as well. Attached to upper arm **1312** are two Z-channels **1314** and **1316**. Lower arm **1302** extends radially out from axis **1308** farther than does upper arm **1312**. Thus, each arm, arm **1302** and arm **1312** may move independently of each other without the respective pair of Z-channels **1304**,

1306, **1314**, and **1316** of each arm, arm **1302** and arm **1312**, colliding. Robotic hands (not shown) may be used on each pair of Z-channels **1304**, **1306**, **1314**, and **1316.** The robotic hands mounted on the outer Z-channels of Z-channel pairs **1304**, **1306**, **1314**, and **1316** may extend outward as necessary from respective outer Z-channels of Z-channel pairs **1304**, **1306**, **1314**, and **1316** such that each robotic hand may reach and grasp cassettes from the outer library storage module **1310**. Robotic hands (not shown) mounted to the inner Z-channels of Z-channel pairs **1304**, **1306**, **1314**, and **1316** service cartridges mounted on inner walls (not shown).

Figure 14 illustrates an alternate embodiment in which four concentric independently rotatable arms are present within a library storage module **1410** in accordance with a preferred embodiment of the present invention.

Figure 15 shows a schematic diagram of four independently rotatable arms with off-centered axes of rotation in accordance with a preferred embodiment of the present invention. Each arm (not shown) are attached to a different rotation point, points **1502**, **1504**, **1506**, and **1508**. Each arm consists of a 4410 type cantilever beam arm holding a z-column. The arms are mounted to library floor **1550** off-center such that each arm assembly has its own theta rotation point as shown by rotation points **1502**, **1504**, **1506**, and **1508**. These separate rotation points **1502**, **1504**, **1506**, and **1508** enables independent theta movements of multiple robots, although each robot would have its own zone of operation as shown by zones

1501, **1503**, **1505**, and **1507**. Zones **1501**, **1503**, **1505**, and **1507** are overlapping zones and provide for "pass through". Total redundancy may not be achieved, but more jobs per hour per silo is accomplished. The somewhat elliptical sweep of the robotic hand is counteracted by a variable reach depth, adding size to the hand assembly, or a linkage designed to pivot the hand out further as the arm gets further from the LSM wall.

The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.